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STRENGTHENING OF REINFORCED CONCRETE BEAMS USING CFRP SHEET BY END LOCKING TECHNIQUE

[1]Ms.K.Dhivya, [2]Ms.T.Thilagalakshmi

[1]Assistant Professor (Senior Grade), [2]P.G Scholar, M.E Structural Engineering
[1]Department of Civil Engineering,
[1]Sethu Institute of Technology, Kariapatti, VirudhunagarDt, Tamilnadu, India

Abstract: Strengthening techniques of reinforced concrete (RC) beams are used to meet the current design requirements, serious errors made in design calculations, and poor construction practices. CFRP has significantly improved the flexural capacity of strengthened beams especially when grooving technique has been employed. This project discusses the result of an experimental investigation conducted on CFRP (Carbon Fiber Reinforced Polymer).The tests demonstrate that this innovation with end self-locking can overcome the main shortcomings in reinforced concrete beams strengthened by externally-bonded CFRP.It is by means of avoiding end debonding and restraining the later development of intermediate crack debonding. This investigation consists of conventional RC beam, CFRP wrap RC beam and CFRP wrap by end locking RC beam and investigate the ultimate flextural strength, failure modes of beam and deflection of beams. It is capable of simulating the overall responses of the complicated structural system containing debonding process, failure mode and ultimate strength.

***Keywords*–Strengthening, CFRP wrap, Debonding, End locking technique**

I. INTRODUCTION

The strengthening of reinforced beam is mainly needed usually caused by problems due to degradation of characteristics of materials with time, reduction in cross section, corrosion, wrong initial design or the increase in the load demand on the building when its utilized for a new purpose other than it was intended to. These problems may lead to the existing steel bars in the beam to become unsafe or insufficient. In such cases, there are a number of solutions to be applied to make them safe or sufficient enough to bear the load. They are **Reinforced Concrete Jacketing, Steel Jacketing and FRP Jacketing**. The above techniques are used for the strengthening the reinforced beam. The most common and effective technique to strengthening the reinforced members is using FRP material. The **Fiber Reinforced Polymer (FRP)** application is an effective method to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials. Strengthening of concrete structures must be considered when the existing structure deteriorates or any alteration to the structure has to be made due to which the structure may fail to serve its purpose. When concrete structural strengthening is to be undertaken all failure modes must be evaluated. Strengthening a structure for flexure may lead to shear failure instead of giving the desired increased load bearing capacity. Composite are combinations of the two materials. The one of those material is called reinforcing phase. It may be in the form of fiber, sheets or particles. Those materials are embedded in the other material is called matrix phase. The reinforcing phase consists of fiber provides strength and stiffness. The most used common types of fiber are Basalt, **Carbon, Aramid and Glass**. When concrete or masonry structures are found to have insufficient strength, externally bonded reinforcement has proven to be a good option. Over the last decade, externally bonded fiber-reinforced polymer (FRP) composite systems have been the best alternative to conventional methods for strengthening and retrofit. Minimal surface preparation is required and installation is simple and quick. Generally temporary support while the adhesive gains strength is unnecessary. Speed is particularly important for applications such as bridges, because of the high costs of possession times. The weight of the structure and the dimensions of the member are not significantly increased. Carbon Fiber Reinforced Polymer has become a notable material in structural engineering, being used in number of field applications including: strengthening concrete, masonry and steel, cast iron, and timber structures. Carbon fiber has also become an increasingly popular uses in retrofitting old buildings and bridges by reinforcing existing parts of the structures. While comparing the all fibers carbon fiber has high tensile strength and high elastic modulus with low density.Carbon Fiber Reinforced Polymer (CFRP) is an advanced composite material with the advantages of high strength, lightweight, no corrosion and excellent fatigue resistance. These are composite materials which rely on the carbon fiber to provide the strength and stiffness while the polymer provides a cohesive matrix to protect and hold the fibers together and provides some toughness.

II. LITERATURE SURVEY

Chao-Yang Zhou et al., (2020)experimented and made a Strengthening RC beams using externally bonded CFRP sheets with end self-locking. When laminates of fiber reinforced polymer (FRP) are just bonded on the substrate of reinforced concrete (RC) members for strengthening, debonding failure often happens prematurely and suddenly on the FRP-concrete joints. It is unbeneficial to efficient employment of FRP and reliable service of the structures.A novel method with simple device is invented to lock the end of flexible strip. The relevant hybrid anchorage technology of FRP strip is developed and investigated in this paper. The mixed system combines the externally-bonded FRP with the end anchorage. Its capability and accuracy are validated by comparisons between the numerical predictions and the test results.

A.GhaniRazaqpur et al., (2019)experimented and made a study on Strengthening of RC beams with externally bonded and anchored thick CFRP Laminate. Premature debonding of externally bonded FRP laminate from retrofitted reinforced concrete (RC) members can lead to inefficient use of FRP and can limit the level of strength increase that can be achieved. In this investigation, π-CFRP anchors are used in an attempt to delay the onset of premature debonding and to achieve higher strength in beams retrofitted with a 1.2mm thick and 50mm wide CFRP laminate. The π-shaped anchor tested in this investigation can delay IC debonding effectively, but the proper number and spacing of anchors must be carefully selected. The proper procedures for the selection need to be developed in future investigations.

Haya H. Mhanna et al., (2019) experimented and made a Shear Strengthening of Reinforced Concrete Beams Using CFRP Wraps. The need to retrofit existing reinforced concrete (RC) structures have increased over the decades due to corrosion of steel reinforcement inside the concrete, neglect and overuse, and increased loading. Experimental and numerical studies in this research field showed that using fiber-reinforced Polymer (FRP) materials to strengthen RC members in shear, flexure, and column confinement applications is an effective method to retrofit RC structures. The failure mode of completely wrapped beams is FRP rupture, which is more favourable compared to the sudden debonding of the FRP laminates of the U-Wrapped beams. In the case where beams cannot be completely wrapped, the U-wrapping scheme is a feasible option. However, for the U-Wrapped beams to reach the same performance of the completely wrapped beams, CFRP laminates should be properly anchored to avoid the brittle debonding.

Maysoun M. Ism et al., (2019)experimented Flexural behavior of continuous RC beams strengthened with externally bonded CFRP sheets. The survey of the previous literature showed the need for research studies on the behaviour of strengthened continues reinforced concrete (R.C.) beams. This paper aims to study the effect of strengthening schemes on the flexural behavior of continuous R.C. beams under a wide range of parameters. According to the previous numerical and experimental investigations discussing the flexural behavior of continuous R.C. beams, the failure mode at hogging zone in case of using one layer is a rupture, while in case of two layers is de-bonding.

A.S.D. Salama et al., (2019) experimented and made a Performance of externally strengthened RC beams with side-bonded CFRP sheets. The conventional method of strengthening reinforced concrete (RC) beams in flexure is via bonding carbon-fiber reinforcement polymer (CFRP) laminates to the beam's soffit. However, the beam's soffit could be narrow or inaccessible for strengthening. The experimental results showed that the external side-bonded strengthening technique is slightly less effective in enhancing the flexural properties and strength of RC beams than that of the conventional soffit strengthening technique.

III.EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Concrete

The concrete mix proportion designed by IS method to achieve the strength of 25 N/mm^2 and was 1:1.9:3.2 by weight. The designed water cement ratio was 0.42. Concrete cube specimens were cast for each batching and tested at the age of 28 days to determine the compressive strength of concrete. The average compressive strength of the concrete was 31.6N/mm^2.

3.1.2 Carbon Fiber

The unidirectional carbon fibre called Sikawrap – 230 C/45, fabricated by SIKA India Inc was used in this study. It is a low modulus CFRP fibre having modulus of elasticity of 230kN/mm^2 and the tensile strength was 4300 N/mm^2. The thickness and width of the fibre was 0.131mm and 600mm respectively. It is fabric type and can be tailored into any desired shape.

3.1.3 Adhesive

The saturantSikadur – 330 supplied by SIKA India Inc was used in this study to get sufficient bonding between steel tube and carbon fibre. It is a two part systems, a resin and a hardener and the mixing ratio was 100:25 (B:H).

3.1.4 Reinforcement

The commercial HYSD reinforcing bars supplied by **Rana Tor India**was used in this study. 8mm diameter bars were used in tension and compression. The yield strength of bars was 415N/mm^2 was chosen from the experimental values.

3.2 SPECIMEN FABRICATION

The inside portion of the steel mould having a dimension of 900x100x150mm was thoroughly cleaned and coated by a crude oil prior to filling with concrete in order to obtain the smooth surface. For all the mixtures the basic ingredients of the concrete such as cement, sand and coarse aggregate were weighed in dry condition and the mixtures were mixed together. The steel reinforcement was placed with required cover in the mould followed by the mould was filled by the concrete by layer by layer and the each layer was fully compacted by the needle vibrator to ensure the concrete free from voids and flaws is shown in Figure 3.1. The reinforcement detail was shown in Figure 3.2.

Figure 3.1 Reinforcement in Steel Moulds

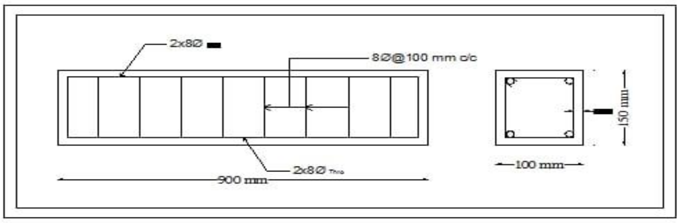

Figure 3.2 Reinforcement Details

Then the specimens were demoulded after 24 hours of casting and they were allowed to membrane curing for 28 days. The quality of the each batching was controlled by obtaining its 28 days compressive strength. Surface preparation of the metal substrate is very important to achieve good bonding between steel tube and CFRP fabrics. The strength of the adhesive bond is directly proportional to the quality of the surfaces to which it is bonded. So the bottom surface of the RC beam was rubbed buy the wire brush to make the surface rough one. After that all rubbed surface was cleaned by acetone. Finally carbon fibres were bonded to the exterior surface of the RC beam members with the different wrapping schemes. During wrapping of fibre fabrics, the resin and hardener are correctly proportioned and thoroughly mixed together and the excess epoxy and air were removed using a ribbed roller moving in the direction of the fibre is shown in Figure 3.3.

Figure 3.3 Bonding between RC beam and CFRP using Laminating Roller

3.3 EXPERIMENTAL SET-UP

Three point loading system was adopted for the tests. A Data Acquisition System was used to store the data such as load and corresponding vertical deflection. The beams were mounted over two pedestals and the concentrated loads were applied by means of 40T Universal Testing machine (UTM). The load at which the concrete has started to rupture, the failure load of the specimens and also the nature of failure modes were noted for each beam. The experimental setup is shown in Figure 3.4.

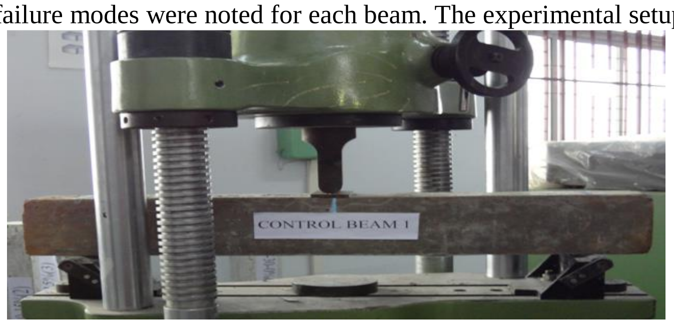

Figure 3.4 Load set-up

IV. RESULTS AND DISCUSSION

4.1 BEAM DESCRIPTION

Four beams, excluding three control beams were strengthened by CFRP composite with one and two layers. The size of the beams was 900x100x150mm. To identify the specimens easily, the beams were designated with the names such as FWB-1, FWB-2, FWB-EL-1 and FWB-EL-2. For example, the beams FWB-1, and FWB-EL-1 indicate that the beam were strengthened by one layer of CFRP composites with and without end locking technique respectively. All the control beams were designated as CB1, CB2 and CB3.

4.2 FAILURE MODES

All the beams were placed at the supports and also centered to ensure symmetric loading prior to apply loading. To understand the influence of CFRP on the flexural behavior of RC members, the beams were loaded to until failure in quasi-static manner. All the control beams were failed by shear failure alone is shown in Figure 4.1.

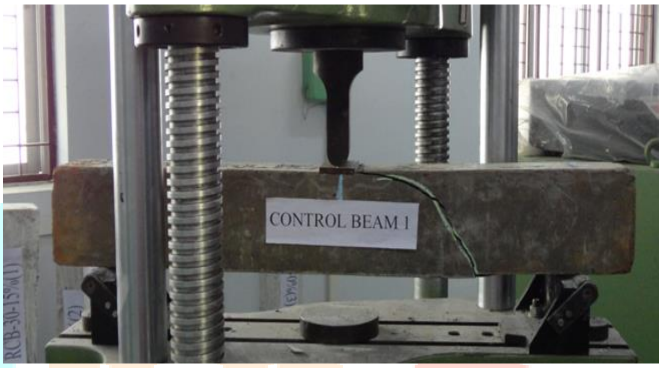

Figure 4.1 Failure mode of Control Beam 1

The beams were strengthened by one and two layers of CFRP without end locking were failed by bending cum shear failure alone which is shown in Figure 4.2 and 4.3, in addition no rupture of fibre was observed. However the predominant failure mode was shear failure. This is a result of the fact that due to the limitations of the loading frame, the clear span of the beam is considerably low when compared to its cross sectional area of the beam. Therefore the depth of the beam had become more when compared to the clear span of the beam as a result the shear failure has become a predominant failure mode one.

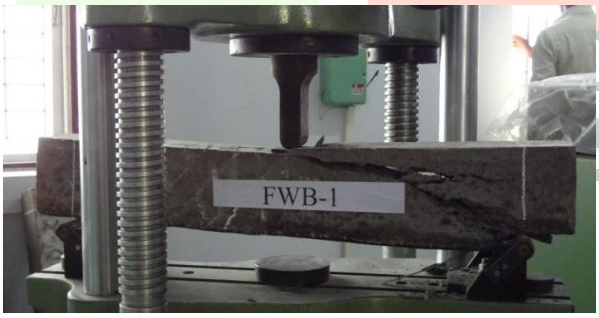

Figure 4.2 Failure mode of FWB-1

Figure 4.3 Failure mode of FWB-2

In the case of beams FWB-EL-1 and FWB-EL-2, the introduction of end locking change the failure mode. The beam was failed by rupture of fibre is shown in Figure 4.4. From the observation it can be confirmed that the presence of end locking significantly increase the bond between the CFRP and the RC beams.

Figure 4.4 Failure mode of FWB-EL-2

4.3 LOAD – DEFLECTION BEHAVIOUR

Load-deflection behavior of CFRP strengthened beams with respect to control specimen is shown in Figure 4.5 to Figure 4.7.Until reach the failure load of control beam, all the strengthened beams with both the wrapping schemes exhibited linear elastic behavior, followed by inelastic behavior when increasing the load. As expected external bonding of CFRP significantly reduce the deflection and also enhance the stiffness of the beam compared to the control beam. The beam strengthened by full wrapping with one and two layers CFRP significantly control the mid-span deflection compared to that of control beam as shown in Figure 4.6 and Figure 4.7.

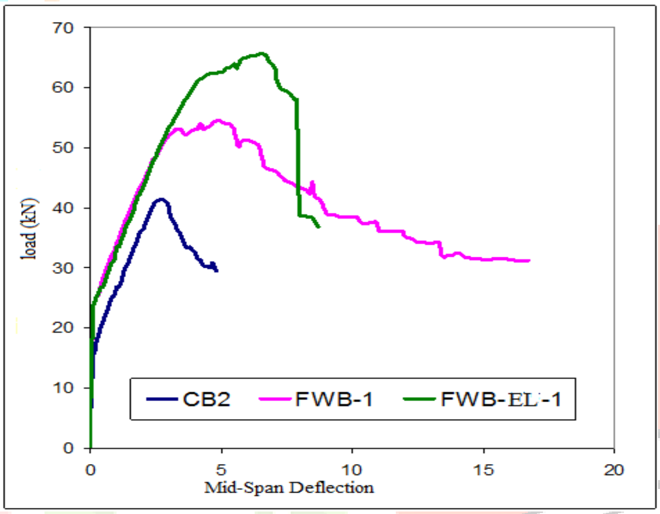

Figure 4.5 Load-Deflection comparison for CB1, FWB-1, FW-EL-1

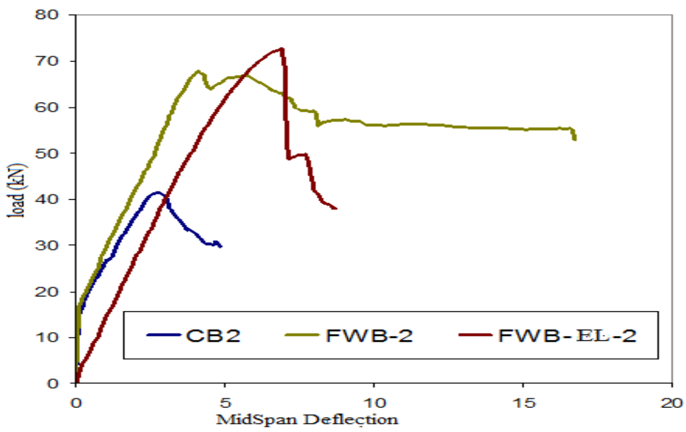

Figure 4.6 Load-Deflection comparison for CB2, FWB-2, FW-EL-2

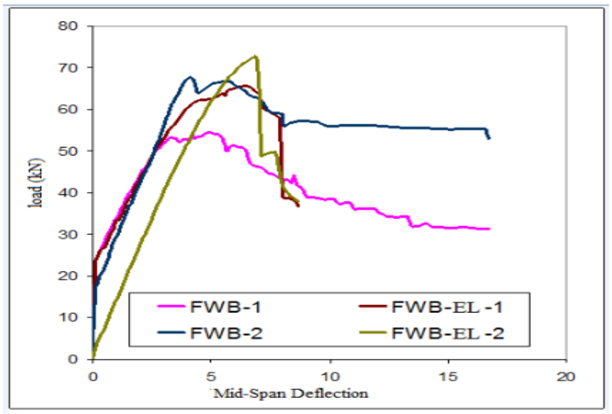

Figure 4.7 Load-Deflection comparison for FWB-1, FW-EL-1, FWB-2, FW-EL-2

Comparing the behavior of beam FWB-1 and FWB-2 to that of control beam (CB2), all two beams showed significantly enhancement in stiffness and deflection control especially the behavior of FWB-2 was outperformed. At the respective failure load of control beam, the mid span deflection of beams FWB-1 and FWB-2 were 16.9mm and 21mm and this deflection was 3.5 times lesser than that of control beam.Compared to control beam, enhancement in deflection control of beams FWB-1 and FWB-2 were 150% and 256% respectively. The above difference in deflection control attributed to the presence of CFRP layers, while increasing the number of layers, the fibre lie in the outer limits provides required tensile capacity during large bending. In the case of beams FWB-EL-1 and FWB-EL-2, the introduction of end locking, further reduce the deflection especially in the case beam FWB-EL-2. The beams FWB-EL-1 and FWB-EL-2 enhanced its defection control by 7% and 8% when compared to the CB2.

4.4 FLEXTURAL STRENGTH

The main objective of this study is to enhance the flexural capacity of the RC beams using CFRP fabrics. As expected, the external bonding of fibre significantly increases the moment carrying capacity of the RC beams especially for the beam strengthened with end locking. Figure 4.8 shows the enhancement in moment carrying capacity of beams strengthened by with and without end locking by CFRP with respect to control beam.

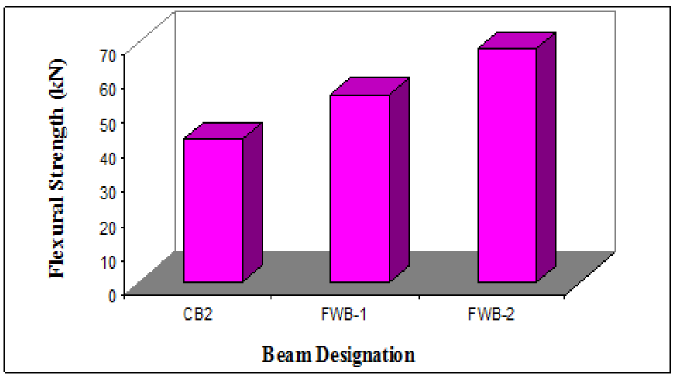

Fig 4.8Flexural strength of beams strengthened by CFRP without End Locking

The results obtained from these strengthening technique revealed that, the presence of CFRP in the outer limits considerably increase the flexural strength of the beam especially for the beam strengthened by two layers with end locking. The enhancement in moment carrying capacity of beams FWB-1 and FWB-2 were found to be 25%, and 47% more than that of control beam (CB2). The increase in strength is attributed to the CFRP lies in the outer limits considerably provide the tensile strength during bending as a result the flexural strength of the beam was increased.

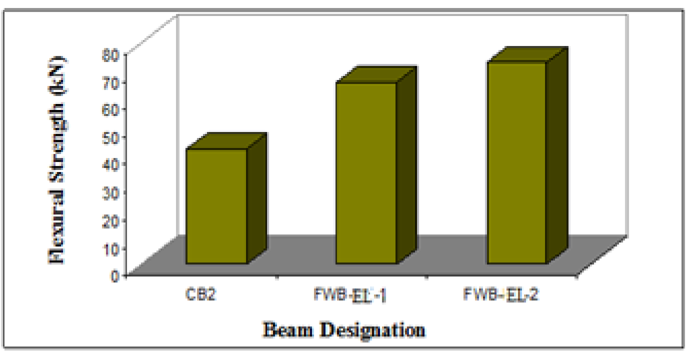

Fig 4.9Flexural strength of beams strengthened by CFRP with End locking

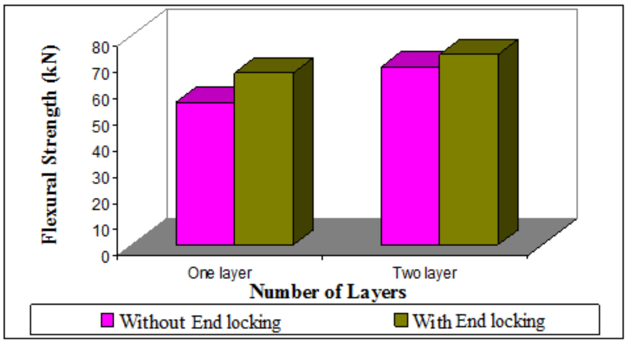

Fig 4.10Flexural strength of all beams strengthened by CFRP –Comparison

It can be seen from Figure 4.8 and 4.9 that, the beams FWB-EL-1 and FWB-EL-2 increased their flexural strength by 25%, and 47% respectively when compared to the CB2. Comparing the flexural strength of beam FWB-EL-1 and FWB-EL-2 to that of FWB-1 and FWB-2, beam FWB-EL-1 and FWB-EL-2 enhanced its flexural strength by 4% and 3%. The increase in strength when introducing the end locking was due to As said earlier, the end locking lie in the outer limit increasing the bond between the concrete and CFRP as a result the substantial load transfer was occurred. Another possible reason was introduction of end locking reduce theeffective span of the CFRP as a result during bending tensile strength provide by the CFRP was increased.

V. CONCLUSION

- The experimental study on this topic should be carry over to obtain the results using various testing methods.
- The failure modes, deflection and ultimate flextural strength are found out under testing methods of beam.
- Four beams, excluding three control beams were strengthened by CFRP composite with and without end locking technique.
- From the observation it can be confirmed that the presence of end locking significantly increase the bond between the CFRP and the RC beams.
- While increasing the number of layers, the fiber lie in the outer limits provides required tensile capacity during large bending.
- After introduction of end locking, further reduces deflection especially in the case beam FWB-EL-2.
- The main objective of this study is to enhance the flexural capacity of the RC beams using CFRP fabrics.
- The increase in strength is attributed to the CFRP lies in the outer limits considerably provide the tensile strength during bending as a result the flexural strength of the beam was increased. The increase in strength when introducing the end locking the bond between the concrete and CFRP as a result the substantial load transfer was occurred.
- Another possible reason was introduction of end locking reduce the effective span of the CFRP as a result during bending tensile strength provide by the CFRP was increased.

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